

## ADAPTIVE ALGORITHM FOR CALIBRATION OF ARRAY COEFFICIENTS

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### ABSTRACT

*Phased array antennas are deployed in electronic systems where high beam directivity and/or electronic beam scanning is desired in applications ranging from radar systems to smart antennas in wireless communication where errors such as random and/or correlated fluctuations present in the excitation coefficients of a phased array can degrade its performance. The errors due to random environmental changes, mechanical variations, assembly inaccuracies, mutual coupling effects and mistune or failure of amplifiers and phase shifters etc may cause undesirable effects such as decrease in directivity, increase in side lobes and steering the beam in wrong direction. In this paper, an adaptive algorithm for the excitation of coefficients of the phased array is demonstrated. Here a linear array is considered and the knowledge of the reference signal generated by the desired array at the near-field sensors is assumed and the fluctuations in the coefficients of the actual array are corrected by means of a gradient based least mean square adaptive algorithm. Requirements for the algorithm to converge, its performance without receiver noise and the effects of the dither parameters are studied.*

**KEYWORDS:** Dithering, Antenna array, phased array, least mean square & near field sensors.

### I. INTRODUCTION

Phased array antennas [1] have acquired a great demand in many applications ranging –from radar systems to smart antenna systems where high beam directivity and electronic scanning of beam in specific and/or different directions is desired. Within the visible or infrared spectrum of electromagnetic waves it is also possible to construct optical phased arrays. They are used in wavelength multiplexers and filters for telecommunication purposes, laser beam steering, and holography. Synthetic array heterodyne detection is an efficient method for multiplexing an entire phased array onto a single element photo detector.

Irrespective of high costs and complex structure of phased array antennas, there are many advantages which include low probability of interception, high jamming resistance, multifunction operation by emitting several beams simultaneously, ability to permit the beam to jump from one target to next in a few milliseconds etc.

But it has well known that random and fluctuation errors due to correlation present in the excitation coefficients (amplitude, phase) of phased arrays may degrade its radiation pattern that affects the desired characteristics. The desired characteristics include decrease in directivity, increase in side lobes and beam steering in wrong direction.

This degradation in desired characteristics may particularly be severe in applications of high performance arrays such as in satellite communication where high directivity and low side lobes are often required. Degradation in radiation pattern requires high transmitting power or causing

interference to neighboring satellites. The sources of errors include those introduced by the random variations in the radio propagation channel, mechanical variations of the phased array set up, inaccuracies caused during assembly, mutual coupling effects between neighboring elements in the array etc.

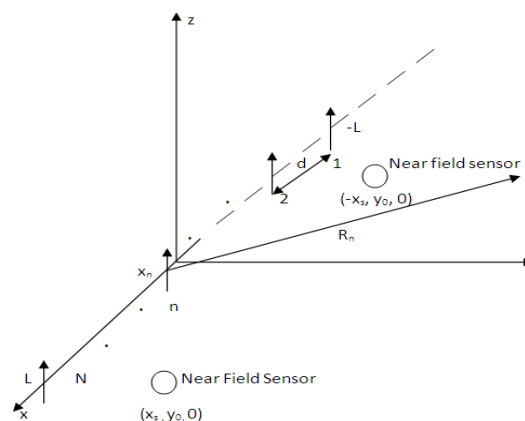
The methodology adopted in this paper is given based on the linear array with two near field sensors where the coefficients are considered to be perturbed due to the environmental effects around the antenna. Later they are dithered and then corrected using the adaptive algorithm of least mean square technique.

The results are presented for a broad side Taylor array of 32 elements with side lobe level of -25 dB. The total length of the array is assumed to be  $2L = 15.5\lambda$  with element spacing of  $0.5\lambda$ . The normalized current distribution of true and actual array with respect to the element number plotted and for the purpose of illustration, we perturb the true coefficients randomly with the magnitude varied on a dB scale using log-normal distribution with an RMS deviation of 2 dB and the phase varied uniformly with an RMS deviation of  $10^\circ$ . The current distribution of perturbed true and actual array along with the dithering applied is also plotted. Later the near field sensed magnetic field and far field magnetic fields are plotted showing the degradation in the sidelobe level and broadened beamwidth. Then using the adaptive algorithm the performance is improved and results explain themselves that after the correction the performance is almost close that of the true array.

## II. METHODOLOGY

### 2.1. Coefficients in Linear Array

Here a linear array [5], [6], [7] was considered with dipole elements arranged along  $x$ -axis with spacing between the elements as ' $d$ ' as shown in Fig 1. The axis of the dipoles are assumed to lie along the  $z$ -axis the total number of elements are assumed as ' $N$ '. The distance of the observation point from the  $n$ -th element is denoted by ' $R_n$ '. The total length of the array is given by  $2L = (N-1)d$ . Two near field sensors are placed towards 1<sup>st</sup> element and  $N$ th element. The near field sensors are assumed to sample the magnetic field, although the theory developed is equally valid for an electric field sensor.



**Fig 1:** A Uniform Linear Array comprised of dipoles with proposed positions of near field sensors.

In the following, the array coefficients with  $C_n$  is treated as true array (or desired array) and that with  $\tilde{C}_n$  as actual array. The normalized complex current excitation coefficient of the  $n$ -th element is denoted by  $C_n = a_n e^{i\psi_n}$ , where  $a_n$  and  $\psi_n$  are the magnitude and phase respectively. Now for automatically correcting the coefficients  $\tilde{C}_n$ ,

We introduce dithering [10][11][12][13] and [14] which means introducing pseudo random fluctuations into magnitude and phase of the coefficients for both true and actual array. Here we assume a log-normal distribution with a standard deviation of  $\sigma$  dB for the magnitude and a uniform distribution with a maximum deviation of  $\Delta$  for the phase. The dithered magnitudes and phases of the true array are

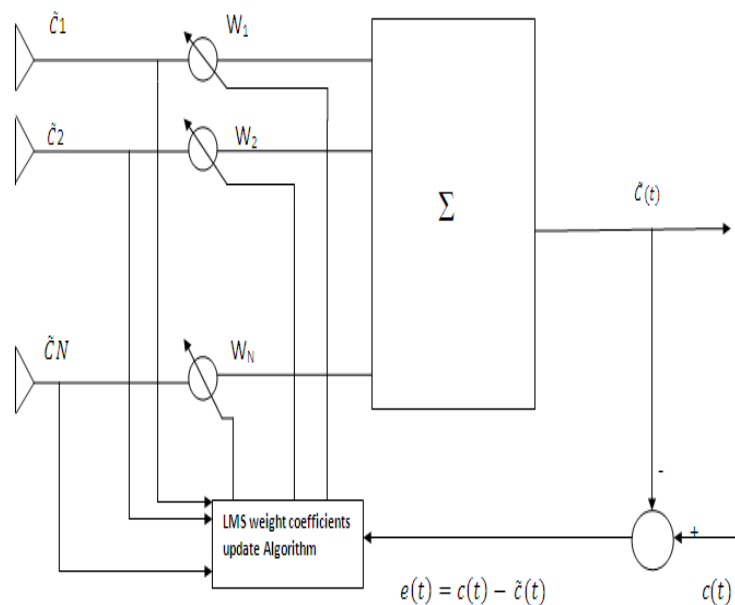
$$\tilde{a}_n = a_n e^{\alpha v_n}, \quad \alpha = 0.05 \ln(10) \sigma$$

$$\tilde{\psi}n = \psi n + \mu n \Delta$$

Where  $v_n$  is a unit-variance, zero mean Gaussian random variable and  $\mu_n$  is a uniform random variable. Now, the dithered magnetic field vector is computed using the complex current distribution of true dithered and actual dithered coefficients. These dithered magnetic fields due to the true and actual array are assumed to be observed at the near field sensors. As two near field sensors are placed near the first and the N-th, vector addition of the magnetic fields is considered. Finally, the error signal which is obtained by subtracting the true dithered coefficients from actual dithered coefficients is minimized using a gradient based adaptive algorithm that can be devised to nullify unwanted deviations.

## 2.2. Adaptive algorithm

An adaptive algorithm [2][3][4][8] and [9] is an algorithm that varies the weights of the phased array based on the received data in order to improve the signal strength and reduce the bit error rate. The algorithm is crucial in steering the main beam of the antenna array. Different algorithms have different characteristics, i.e. different convergence rates, computation complexity, and effectiveness. Least mean square algorithm (LMS) was used in the present work due to its simplicity as it does not require correlation function calculation nor it does require matrix inversions. The block diagram of LMS algorithm for adaptive beam forming is shown in Fig 3.



**Fig 2:** LMS adaptive beam forming network

From the above Fig 2, the actual dithered coefficients sensed by the near field sensors are scaled using corresponding weights computed by the least mean square (LMS) update algorithm based on minimum mean square (MSE) criterion. These outputs are linearly combined such that the error is minimized. The error signal which is obtained by subtracting the linearly combined signal from the reference signal i.e. the true dithered signal is fed to the LMS update algorithm which does successive corrections to the weight vector by iterative process and eventually leads to the minimum value of the mean squared error.

The LMS algorithm initiated with some arbitrary value for the weight vector is seen to converge and stay stable for

$$0 < \mu < 1/\lambda_{\max}$$

Where  $\mu$  is step size which is chosen very small such that the algorithm converges very slowly and may be more stable around the minimum value.

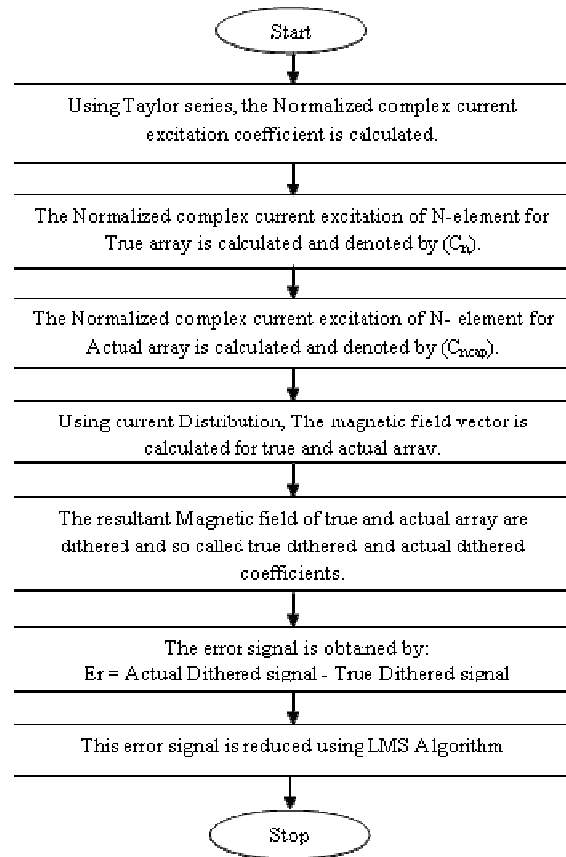


Fig 3: Flow Chart of proposed technique.

### III. SIMULATION RESULTS

Results are presented below for a broad side Taylor array of 32 elements with side lobe level of -25 dB. The total length of the array is assumed to be  $2L = 15.5\lambda$  with element spacing of  $0.5\lambda$ . The simulations are all performed using programming in MATLAB Software. These simulated MATLAB graphs made our analysis easier.

The normalized current distribution of true and actual array with respect to the element number is shown in Fig 4 and for the purpose of illustration, we perturb the true coefficients randomly with the magnitude varied on a dB scale using log-normal distribution with an RMS deviation of 2 dB and the phase varied uniformly with an RMS deviation of  $10^0$ . The current distribution of perturbed true and actual array are shown in Fig 5.

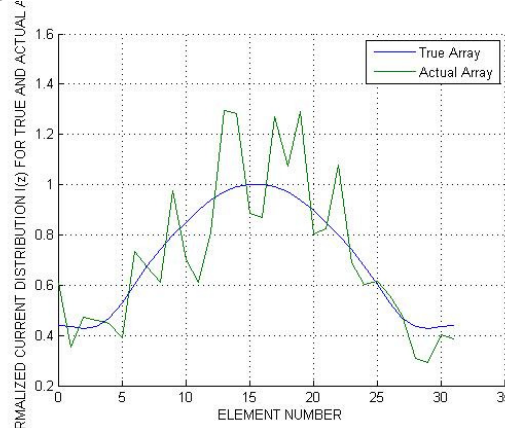
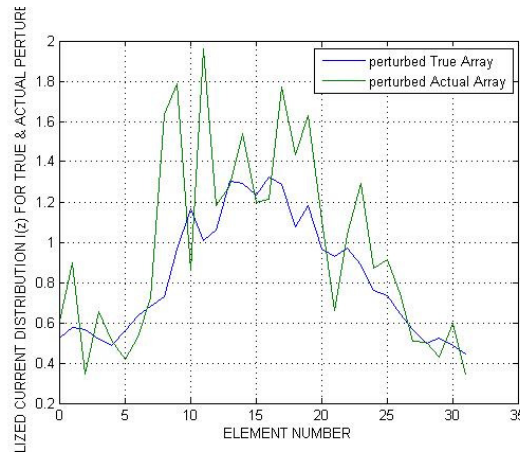
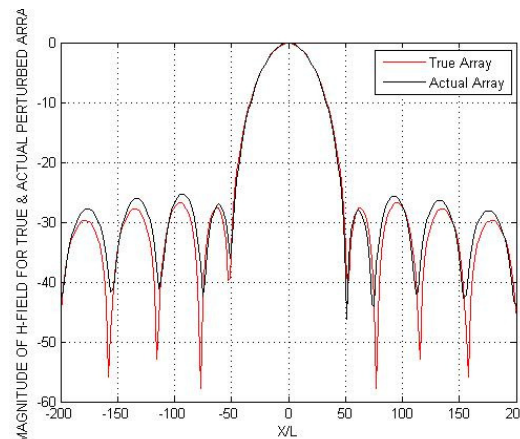


Fig 4: Normalized current distribution of True and Actual perturbed Array.



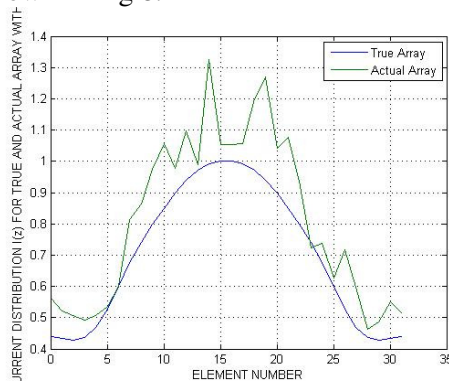
**Fig 5:** Normalized current distribution of True and Actual Array.

The far-zone magnetic field strength for the true and actual perturbed array as a function of lateral displacement  $x$  for  $y = 10R_f$  and  $z=0$  is shown in Fig 6. As a result of fluctuations introduced, the side lobes have increased substantially and the main lobe slightly broadened.

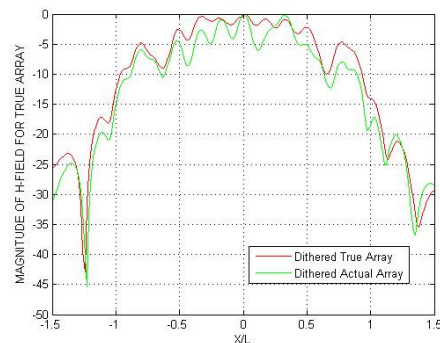


**Fig 6:** Perturbed True and Actual Magnetic fields of a Linear Array.

A near -field sensor is assumed to be located in the  $z = 0$  plane at  $x = x_s = 1.1L$  and  $y = y_0 = R_f/100 = 4.805\lambda$  as shown in Fig 1. The true and actual coefficients are dithered using an RMS deviation of magnitude with 3dB and that of RMS deviation of phase with  $12^\circ$ . The normalized current distribution of dithered true and actual array are shown in Fig 7 and the dithered true and actual near fields are shown in Fig 8.

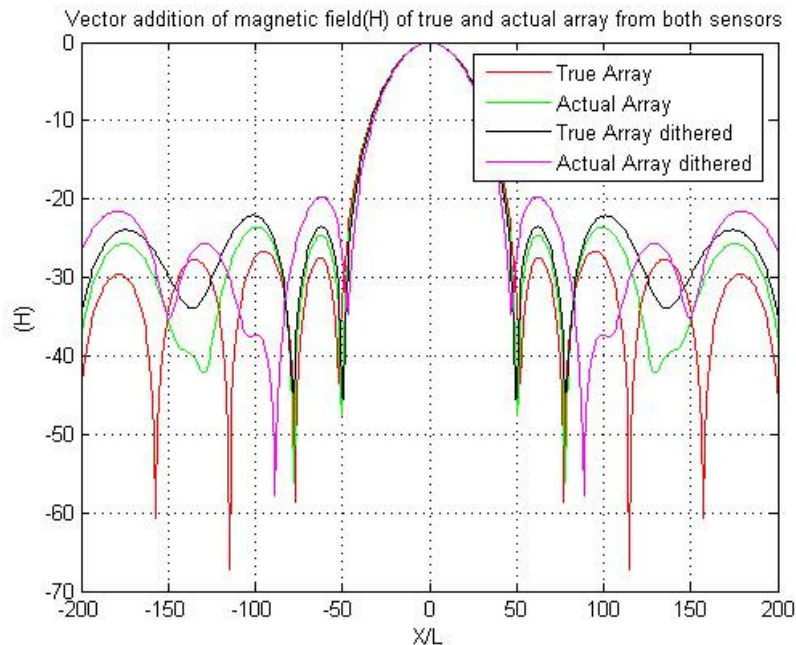


**Fig 7:** Normalized current distribution of dithered true and actual array.

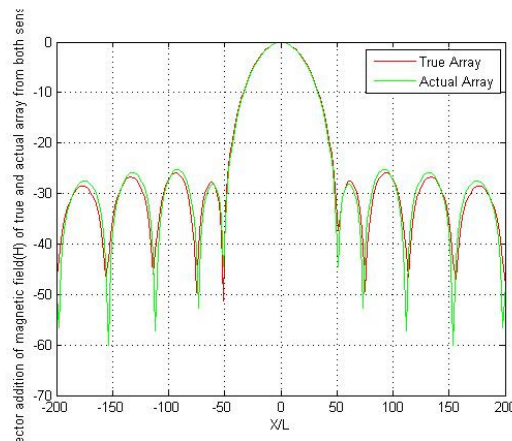


**Fig 8:** Fields at near field sensor 1 for dithered true and actual array.

Another near -field sensor is assumed to be located in the  $z = 0$  plane at  $x = x_s = -1.1L$  and  $y = y_0 = R_f/100 = 4.805\lambda$  as shown in Fig 1. The true and actual coefficients are dithered using an RMS deviation of magnitude with 3dB and that of RMS deviation of phase with  $12^\circ$ . The dithered true and actual near fields are shown in Fig 8 and the vector addition of the fields those sensed by the proposed near field sensors for dithered true and actual array are shown in Fig 9. The Fig 10 shows the application of adaptive correction algorithm applied to the dithered curves of Fig 9. One can notice the approximation of the corrected curve towards the original.



**Fig 9:** Vector addition of the fields sensed by the proposed sensors for dithered true and actual array



**Fig 10:** Corrected Field pattern using adaptive algorithm.

#### IV. CONCLUSIONS

A least mean square type algorithm was presented for correcting the perturbed array coefficients in noise free environment. The robustness of the algorithm has been demonstrated by considering a low side lobe (-25 dB) broad side array with RMS magnitude fluctuations and RMS phase fluctuations in the array coefficients. An adaptive algorithm for automatically correcting the desired excitation coefficients of an antenna array by dithering the coefficients and observing its field in the near zone



by using two near field sensors has been proposed and demonstrated by considering a uniform linear array.

By applying the dithering and correcting algorithm the excitation coefficients are corrected near to their true values. These coefficients suffered from errors earlier and are rectified using our algorithm. By using this algorithm, the performance of the antenna remains close to the specifications even in an environment instead of degraded.

In the future work, adaptive correction of array coefficients by considering the case in noisy environments and also with mutual coupling effects will be analyzed. Further extension can be done with the analysis on Electric fields of the array.

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